Malaysian Journal Of
Civil Engineering

# CONSOLIDATION CHARACTERISTICS OF LATERITIC SOIL TREATED WITH RICE HUSK ASH

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**Article history**
Received
*16 September 2021*
Received in revised form
*07 December 2021*
Accepted
*08 December 2021*
Published online
*31 March 2022*

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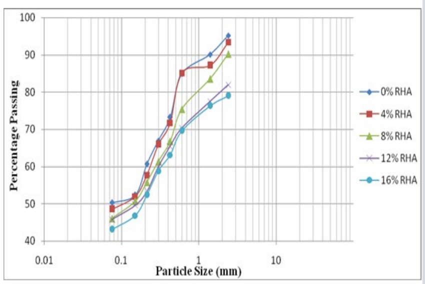
**Graphical abstract**




**Abstract**

Lateritic soil was treated with 0, 4, 8, 12 and 16% rice husk ash (RHA) by dry weight of soil to determine its consolidation properties. Test carried out include; particle size distribution, specific gravity, compaction test with varying compactive efforts (British Standard Light (BSL), West African Standard (WAS) as well as British Standard Heavy (BSH)) and consolidation test. Samples for consolidation test were compacted and then cured for 7, 28 and 56 days; then subjected to one dimensional consolidation testing to observe the influence of curing period and compactive effort on its consolidation characteristics. Index tests showed improved geotechnical properties. The maximum dry density (MDD) for BSL compaction decreased with a rise in RHA content from 1.72 to 1.42 $Mg/m^3$ while optimum moisture content (OMC) increased from 16.5 to 27.3% with rise in RHA doses from 0 up to 16%. Similar trend was observed for WAS and BSH energies. The Pre-consolidation pressure rise with increment in RHA content and also with increase in both compactive efforts and curing period with few exceptions. At 12% RHA content, the Pre-consolidation pressure increased from 65 to 66.5$kN/m^2$ at 7 days and 56 days respectively. Increase in RHA content caused a decrease in Compression Index (Cc) and Swelling Index (Cs). Compression Index also decreased with increase in both compactive efforts and curing period. There was no observed trend in the Swell Index with curing period. As the compactive efforts increased, the swell index decreased. The RHA reduced the Coefficient of Volume Compressibility (Mv) and the Coefficient of Consolidation (Cc). Curing period and compactive effort have no effect on Mv and Cc. Based on the results obtained, curing period of atleast 28 days using up to 12% RHA compacted at energy level of BSH improved the properties of the treated soil and can be use for geotechnical engineering applications like embankment or rural roads. .

*Keywords*: Coefficient of consolidation, Compactive effort, Compression index, Curing period, Gross yield stress, Swelling index,



## 1.0 INTRODUCTION

The uneven settlement which occurs in loaded soil usually causes stresses in structural members which may lead to failure of the entire structure. Past researches [1-6] focused on ways of soil improvement to aid in reducing deferential or uneven settlement of structures under loads by using admixtures such as cement and ash as a means of improving structural safety. Furthermore, other technique such as curing of the admixture improved soil was also tested to further improve the properties of treated soils [7]. Settlement of compressible soils is principally a major factor considered by most foundation Engineers. The settlement of embankments, fly-over junctions, bridge abutments and building structures would not in itself be very serious if the movement were always uniform, but unfortunately they are rarely so and the differential settlement which may occur can result in the development of additional stress which may exceed the design stresses [8].

Lateritic soils are fundamentally the products of tropical or sub-tropical weathering [9]. Two groups of this tropical soils were chemically identified by Sherman [10] and Maigen [11], those in which iron oxide predominant (ferruginous laterite) and others were alumina is predominant (aluminous laterite). In tropical countries including Nigeria, large volume of lateritic gravels and pisoliths occur [12] and used widely as sub-base and base material for low cost roads design for low and also medium traffic. They have also been proposed by Anderson and Hee [13] for use as liner in the construction of landfill because of their low hydraulic conductivity. In the same way, they are regarded as natural assets of significance in geo-environmental applications [14-18] for the reason that they have satisfactory resistance to attack by chemical and minimal desiccation induced shrinkage prospective [15-16].

Too much reliance on the application of industrially made soil stabilizing materials like cement and lime have led to a rise in the cost of construction for engineering purposes [19]. Replacement of this approach with agricultural waste such as RHA for engineering applications will help in mitigating the environment hazard they cause. It has also been reported that cement production procedure generate carbon (IV) oxide ($C0_2$) in large volumes. Therefore, substituting the proportion of cement with a supporting cementitious rice husk ash (RHA) will lessen the generally known environmental problems caused by carbon (IV) oxide ($C0_2$). Several kinds of ashes such as RHA, Sugarcane Straw Ash and Palm Kernel Shell Ash have been developed as cheap admixtures for soil improvement [20]. Research has been going on over the years on the likelihood of using RHA for the reason that it has pozzolanic properties in improving deficient soils [20-24].

This research is justified by the conversion of industrial waste products to valuable materials for engineering applications. The economic conversion of waste products enables for cost effective and environmentally friendly means of construction that would check the global trend of resource depletion. The intention for this study is to appraise the influence of RHA on the consolidation characteristics of lateritic soil in order to regulate its effect during settlement of the soil under load.

## 2.0 METHODOLOGY

### 2.1 Materials

**Soil sample:** The lateritic used in the study was sourced from Shika in Kaduna State. The soil was collected at 0.5-1m depth, and transported to the laboratory in sacks then air dried, using sieved 4.76mm aperture sieve for sieving(British Standard Sieve no. 4) as required by the code of practice [25].

**Rice Husk Ash (RHA):** Rice husk was sourced from Zaria, Kaduna State; Samples were burnt in the open for a period of 7 days. The burnt ash was transported and sieved through a 75µm aperture sieve (British Standard sieve No.200) before usage in the laboratory. The oxide composition test result is shown in Table 1.

**Table 1** Oxide composition of RHA

| Oxide | $SiO_2$ | $Al_2O_3$ | CaO | $Fe_2O_3$ | MnO | $SO_3$ | $P_2O_5$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|
| Concentration (%) | 72.65 | 2.14 | 1.87 | 1.65 | 0.39 | 8.83 | 8.83 | 7.18 |

### 2.2 Methods

**Index properties:** Index properties of untreated soil and the treated soil was performed based on the recommendation of British Standards BS 1377 [25]. Samples were treated with 0 , 4, 8, 12 and 16% RHA by dry weight of soil.

**Compaction :** Compaction test was conducted using three energy levels (BSL, WAS and BSH). Samples were mixed with 0%, 4%, 8%, 12% and 16% RHA by dry weight of soil. Compaction test was done for all the energy levels as proposed by British Standard BS 1377 [25]. For BSL compaction, it involves a 2.5kg rammer, height of fall of 300 mm and 27 blows in three layers using 1000 $cm^3$ mould. WAS compaction involves 4.5 kg rammer, height of fall of 450 mm and 10 blows in five layers using 1000 $cm^3$ mould, in accordance with the Nigerian General Specification [26]. For BSH compaction, it involves a 4.5kg rammer, height of fall of 450 mm each receiving 27 blows in five layers using 1000 $cm^3$ mould. The energy use to compact a unit volume of soil is referred to as compactive effort . Compactive effort is a measure of the mechanical energy imposed on the soil mass during compaction. The corresponding compaction energies for BSL, WAS and BSH are 595.95, 993.26 and 2681.80KN/$m^2$ [25, 26].

**Curing:** Curing was done using polythene bags after compaction at their respective OMCs for all energy levels. Compacted samples were kept inside mould at a controlled temp of in the laboratory for the curing periods of 7, 28 and 56 days separately. After curing, samples were removed from the mould, cut and fit into the consolidation ring. The consolidation test was carried out for each percentage of RHA.

**Consolidation test:** Test in this study was done in agreement with the procedure drawn in section 3 of BS 1377 [25] and Head [27]. The various soil samples were compacted at their respective OMCs prior to consolidation test. Samples compacted at BSL, WAS and BSH energy levels were further cured for the required period of time (7, 28 and 56 days) prior to consolidation test. After compaction, the samples were removed from the mould, cut and trimmed into the consolidation ring before being set up in the consolidation loading frame. An initial pressure of 10kN/$m^2$ was applied and increased systematically to a peak load of 320kN/$m^2$, after which it was unloaded back to 80kN/$m^2$. The test was carried out for each percentage of RHA.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Index Properties

Summary of primary tests done on the soil are displayed in Table 2.

**Table 2** Summary of primary tests

| Property | RHA Contents (%) | | | | |
|---|---|---|---|---|---|
| | **0** | **4** | **8** | **12** | **16** |
| Natural Moisture Content (%) | 10.11 | - | - | - | - |
| Liquid Limit (%) | 44.7 | 46.5 | 48.8 | 50.1 | 51.4 |
| Plastic Limit (%) | 29.9 | 32.4 | 35.8 | 38.3 | 41.8 |
| Plasticity Index (%) | 14.8 | 14.1 | 13.0 | 11.8 | 9.6 |
| Specific gravity | 2.6 | 2.4 | 2.3 | 2.15 | 2.0 |
| AASHTO Classification | A-7(5) | A-7(5) | A-7(4) | A-7(3) | A-5(2) |
| USCS Classification | CL | CL | CL | CL | CL-ML |
| Maximum Dry Density, MDD ($Mg/m^3$) | 1.72 | 1.69 | 1.54 | 1.49 | 1.42 |
| Optimum Moisture Content, OMC (%) | 16.5 | 18.9 | 19.5 | 24 | 27.3 |
| Cation Exchange Capacity, CEC (cmol/Kg) | 6.7 | 6.6 | 6.4 | 6.1 | 5.9 |
| Colour | Reddish brown | - | - | - | - |
| Percentage of fines | 50.29 | 48.48 | 46.01 | 45.74 | 43.08 |

Results of grain size tests for soil–RHA mixtures is revealed in Figure 1 while Figure 2 displays the variation of percentage fine (material passing No. 200 sieve) with RHA content. Experimental result produced present that percentage fines declined progressively with rise in RHA content from 50.29% for the untreated soil to 43.08% at 16% RHA treatment (see Figure 2). The possible explanation for the drop in fine fraction with increasing RHA content may perhaps be credited to flocculation and clustering of the soil–RHA mixtures, that permitted the clay fractions in the soil to form larger soil particles. This behavior is depicted with a shift in the curve (see Figure 1) to the left as the RHA content increased. Related trend was observed by Portelinha et al., [28] and Osinubi et al., [29]. The progressive reduction in specific gravity (see Figure 2) from 2.6 at 0% RHA to 2.0 at 16% RHA could be due to low density of RHA that was use as an admixture in the soil. Related comment was made by Sani et al., [24].

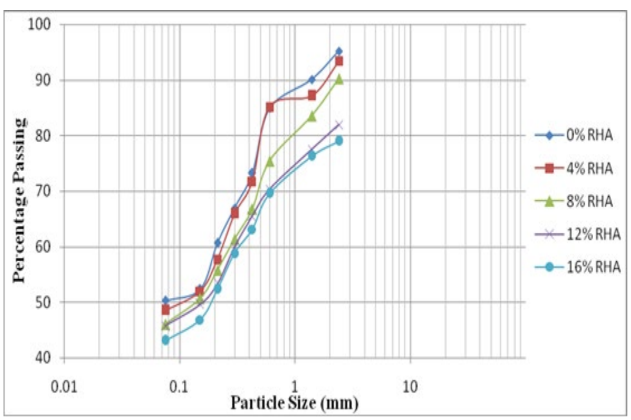



**Figure1** Grain size plots of lateritic soil – RHA mixtures.

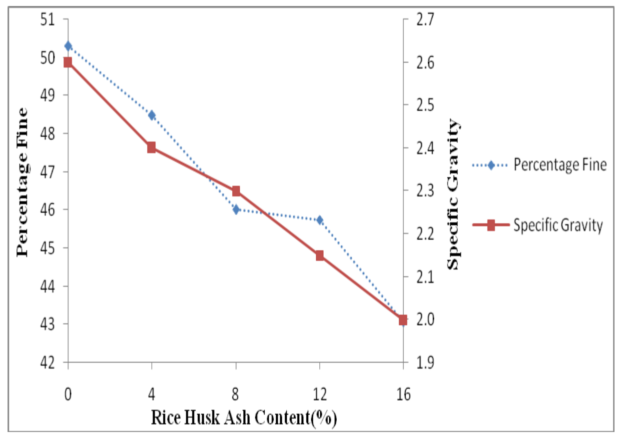



**Figure 2** Percentage fine and specific gravity plots with RHA content

### 3.2 Compaction Characteristics

The effect of RHA on the MDD and OMC is revealed in Figure 3. The MDD largely lessened with rise in RHA content. Similar behavior was recorded by Eberemu [23] as well as Eberemu et al., [30]. The drop in MDD with increasing RHA content could be associated with RHA inhabiting the void inside the soil matrix. Also , could be in line with low specific gravity of the RHA (1.91) when related with that of the lateritic soil (2.6).The MDD for the natural soil at BSL, WAS, and BSH compactive efforts were 1.71, 1.73 and 1.78 $Mg/m^3$ respectively. This indicates that the MDD inclined with higher energies. The MDD values decreased to 1.42, 1.54 and 1.60 $Mg/m^3$ at 16% RHA content for BSL, WAS, and BSH energies in that order. Okafor and Okonkwo [20] reported similar conclusion after noticing related trend in RHA modified soil, but additionally credited the low MDD to the replacement of the soil grains with RHA which outcome was bigger voids henceforth less density.

The effect of RHA on the OMC showed a general trend of incline in the OMC with increasing RHA content (see Figure 3). The increase is probably due to the drop of free silt as well as the clay fraction in the soil establishing a coarser material, a progression necessitating the need for more water, thus additional water is absorbed as RHA dose is increased [20]. As the compactive effort increased, the OMC improved from the natural values of 16.5, 10 and 11% to peak values of 27, 19.5

and 16% at 16% RHA content for BSL, WAS and BSH energies respectively.

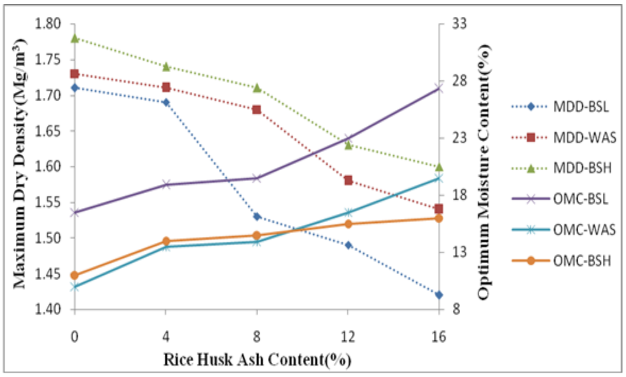



**Figure 3** MDD and OMC plots with RHA content.

### 3.3 Consolidation Characteristics

#### *3.3.1 Pre-Consolidation Pressure*

**Influence of Compactive Effort**

The pre-consolidation pressure is the peak effective vertical overburden pressure that an individual soil sample has sustained earlier. It is measured from the void ratio/logarithm of pressure plot generated from laboratory experiment. The pre-consolidation pressure with compactive effort plot is displayed in Figure 4.

With rise in RHA dose, the pre-consolidation pressure decreased except for the initial stage of 4 to 8% rice husk ash for BSL and WAS effort where an increase was observed before dropping. The decrease could be attributed to structuration which creates a cementation bond for the treated clay particles[32-33]. This demonstrates that with addition of RHA the pre-consolidation pressure values decreased. Another reason for the drop could be credited to the fact that the ash content with marginal pozzolanic behavior might have altered the soil structure (Eberemu et al., [30]. But with increase in compaction energy the pre-consolidation pressure generally increased, pre-consolidation pressure values of 18kN/m$^2$ at BSL, 40kN/m$^2$ at WAS and 50 kN/m$^2$ at BSH efforts were obtained. The pre-consolidation pressure increased by 64, 72, 29, 11, and 28% at 0, 4, 8, 12 and 16% RHA contents, respectively; with increasing the compactive effort from BSL to BSH. This agrees with the findings of Eberemu et al., [30]. They found out that RHA made the soil less difficult to compact and resulted in additional intact placement of the soil leading to the increased values in the pre-consolidation pressure recorded.

**Influence of Curing Period**

Plot of pre-consolidation pressure with respect to curing period is revealed in Figure 5. Generally, the pre-consolidation pressure improved with rising curing period. From 7 to 56 days curing period, pre-consolidation pressure increased from 64 – 66.5 kN/m$^2$ at 8% RHA, 65 – 66.5 kN/m$^2$ at 12% RHA and 73 – 74 kN/m$^2$ at 16% RHA content. These increases correspond to 3.9%, 2.3% and 1.4% at 8, 12 and 16% RHA contents, respectively. Compared to the increase from 7 to 28 days curing period, the incline in pre-consolidation pressure from 28 to 56 days is not as pronounced (which indicates reduced pozzolanic reactivity). Eberemu and Sada [31] reported that pozzolanic reaction continues after mixing of the soil.

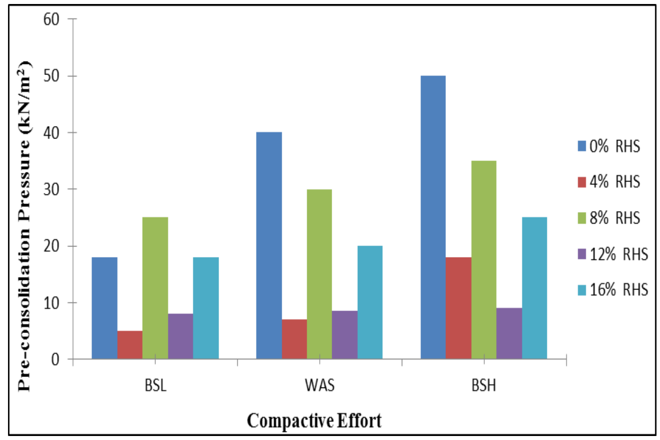



**Figure 4** Pre-consolidation pressure with compactive effort

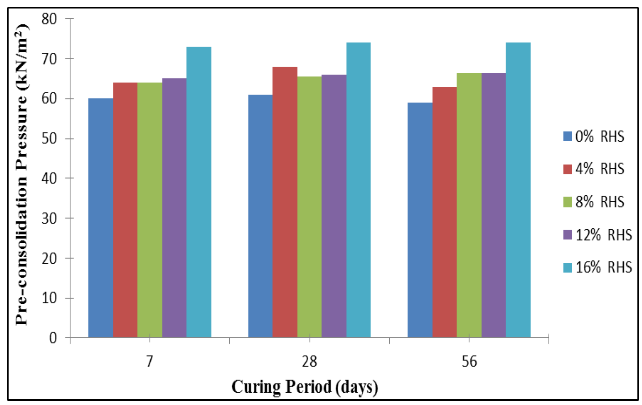



**Figure 5** Pre-consolidation pressure with curing period

#### *3.3.2 Compression index (Cc)*

**Influence of Compactive Effort:**

Figure 6 shows the changes in compression index, Cc with compactive effort. Generally as the RHA content and compactive effort increased, the compression index decreased. Similar trend was reported by Ikeagwuani, [5]. This could be due to the packing of the soil particles together and the reduction in the void spaces within soil matrix with increase in the compaction energy. Values decreased from 0.078 to 0.03 for BSL, 0.067 to 0.003 for WAS, 0.022 to 0.011 for BSH compactive effort. Montohar [34] experimental results revealed that the adding RHA and lime to soil lessened the compression index. Furthermore, Okoro et al, [35] attributed the drop to replacement of fine particles with fines that are non-plastic in nature. The compression index decreased by 8, 4, 19, 27, and 27% at 0, 4, 8, 12 and 16% RHA content, respectively; with rise in the compactive effort. The decrease in compression index could be accredited to the packaging of soil particles thereby reducing the void spaces within the soil matrix.

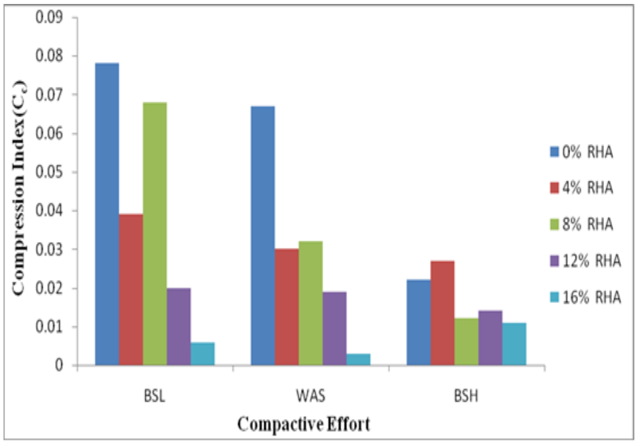



**Figure 6** Compression index with compactive effort plot

**Influence of Curing Period**

Plot of Cc with curing period is revealed in Figure 7. Generally, the Cc marginally declined with rise in curing period. From the 7th to 56th day curing period, the compression indices reduced by 18%, 27% and 26% at 8, 12 and 16% RHA content, respectively. This could be attributed to the time dependent effect of hydration by the pozzolana to form calcium silicate hydrates which are harder compounds, leading to increasing strength and reduction in compression index [36, 37]. This implies that settlement of the soil could be reduced by increased curing period. Also, physicochemical changes within the soil matrix with curing period could be responsible for the recorded results. Similar findings were made in literatures [5,31]

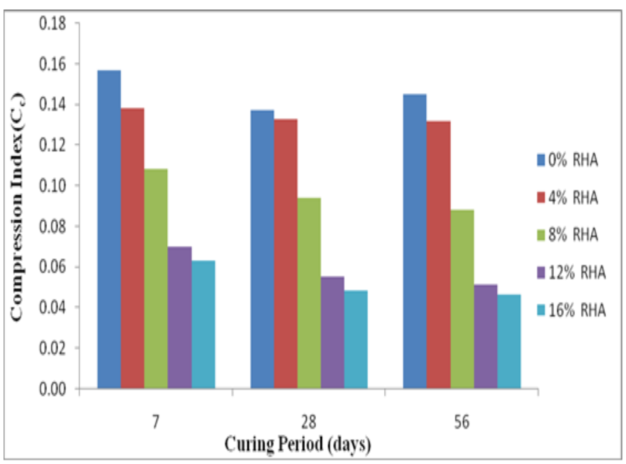



**Figure 7** Compression Index (CC) with Curing Period Plot

***3.3.3 Swell index (Cs)***

**Influence of Compactive Effort**

The plot of swelling index, Cs of the soil with RHA is revealed in Figure 8. Swell index decreased with increase in RHA dose and compactive effort. The values at optimum moisture ranged from 0.58 at 0% RHA to 0.034 at 16% RHA for BSL, 0.03 at 0% RHA to 0.019 at 16% RHA for WAS and 0.02 at 0% RHA to 0.16 at 16% RHA at BSH. Stabilization of soil using admixtures reported by Okoro et al., [35] showed a reduction in the values of swell index by up to 48%. Similar trend was reported by Eberemu [23] as well as Eberemu et al., [30].

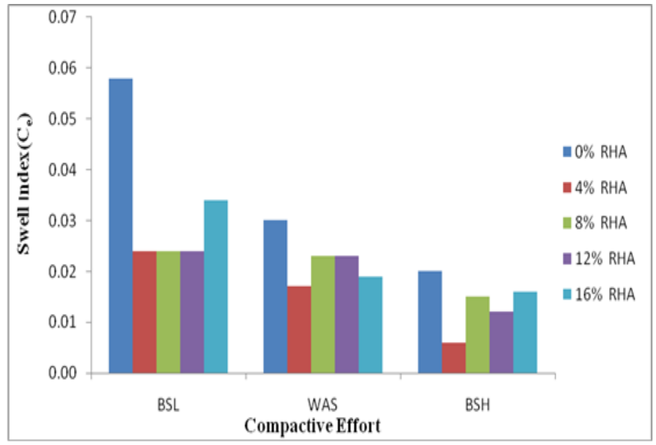



**Figure 8**. Swell index (Cs) with compactive effort plot

**Influence of Curing Period**

The plot of Cs with curing period is revealed in Figure 9. No specific trend was observed due to the impact of curing period on various soil samples treated. This randomness may be due to the already crushed crystal structures that may have been formed for the duration of the curing period by the pozzolanic hydration process. Marginal cation exchange reaction and physicochemical changes within the soil matrix with curing period could be responsible for the recorded results. Similar findings were made in literatures [5,31].

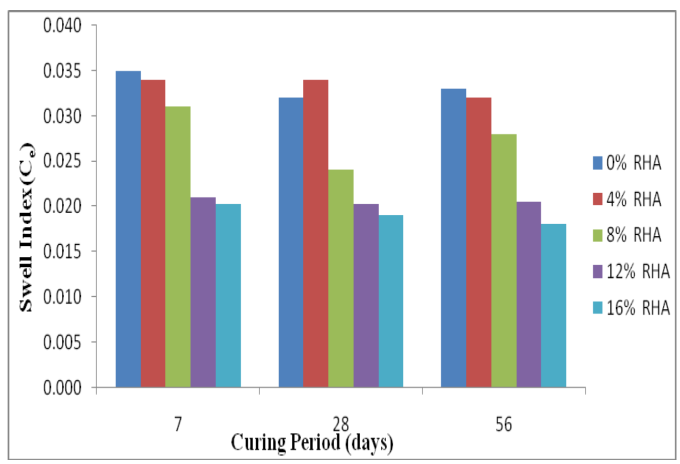
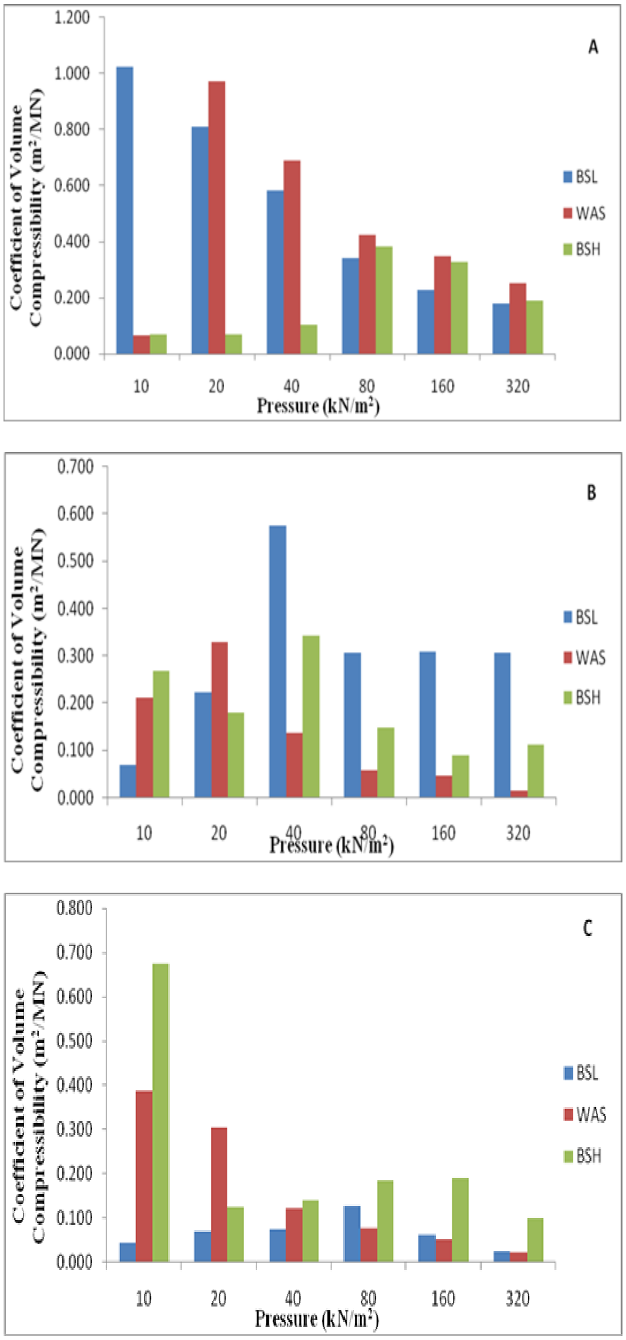



**Figure 9** Swell index (Ce) with curing period plot

***3.3.4 Coefficient of Volume Compressibility (Mv)***

**Influence of Compactive Effort**

The plot of Mv with increase in pressure for BSL, WAS and BSH effort respectively is shown in Figures 10a-e. Generally, Mv lessened with rise in pressure, except for the initial pressure of 10 to 20kN/$m^2$ where the Mv increased slightly. The drop possibly will be credited to first loading increment which made the soils to reach a very huge compression by removal of voids. Also the rearrangement of the soil particles could be responsible for the decreasing trend. Similar observation was reported by Ikeagwuani [5]. Additional increment in the loading pressure, only resulted in slight compression. Santagata et al, [38] in their study observed that volume compressibility of the soils decreases with rise in the pressure applied. Generally, no general trend was established with rise in the compactive effort.



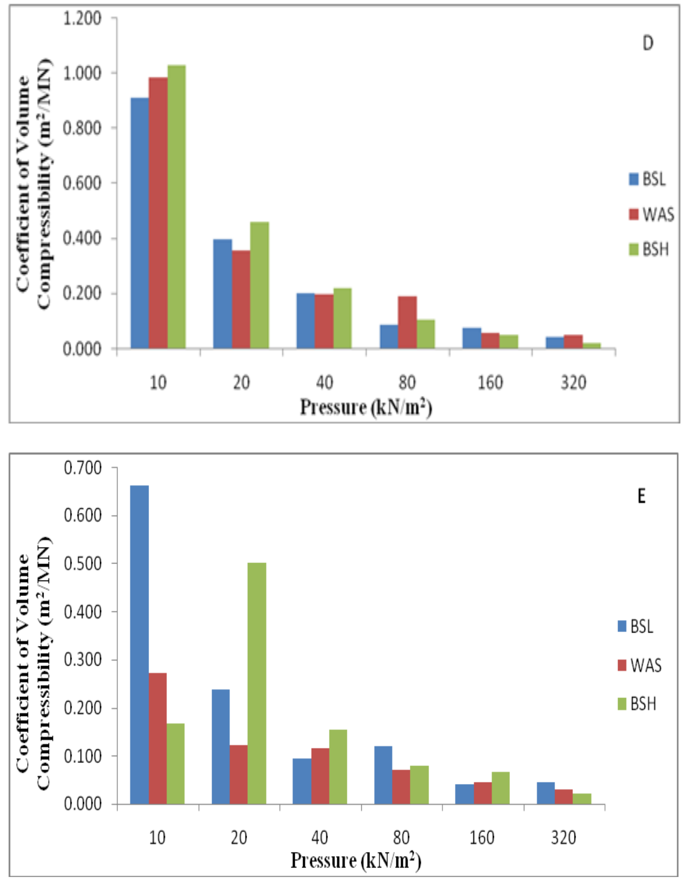
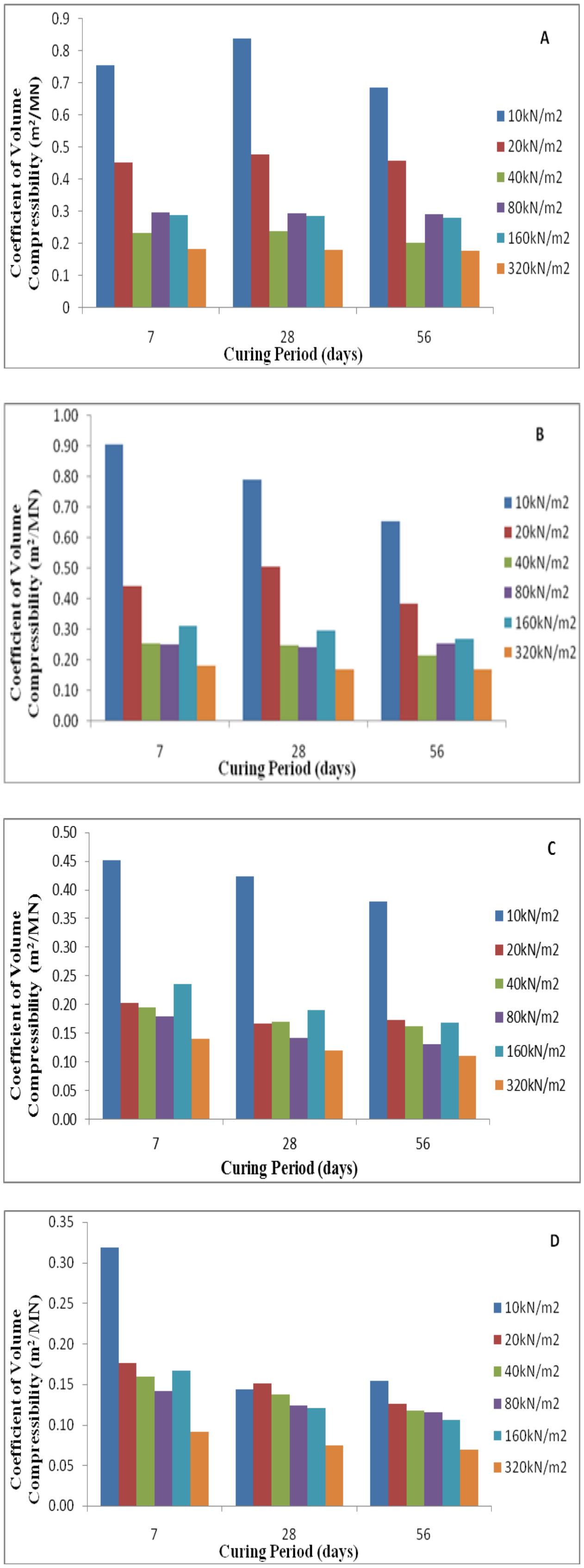




**Figure 10** Coefficient of volume compressibility at varying compactive efforts with pressure for (A) 0%, (B) 4%, (C) 8%, (D) 12% and (E) 16% RHA contents

**Influence of Curing Period**

Figures 11a-e shows the variation of Mv with curing period. At higher RHA contents, from 8% RHA and above, a decrease in the volume compressibility was noticed with rise in curing period for each level of load applied. This is attributed to the curing which is a time dependent process [34]. The values at 8% RHA varied from 0.452–0.380, 0.202–0.173, 0.195–0.162, 0.179–0.13, 0.235–0.168 and 0.140–0.11 at 10, 20, 40, 80, 160 and 320 kN/$m^2$, respectively. When related to the 7days curing period, the values of Mv at 56 days reduced by an average of 25, 30 and 27% at 8, 12 and 16% RHA treatment respectively (for 160 and 320 kN/$m^2$ pressures). Cation exchange reaction and physico chemical changes within the soil matrix with curing period could be responsible for the recorded results. Similar findings were made in literatures [5,31]



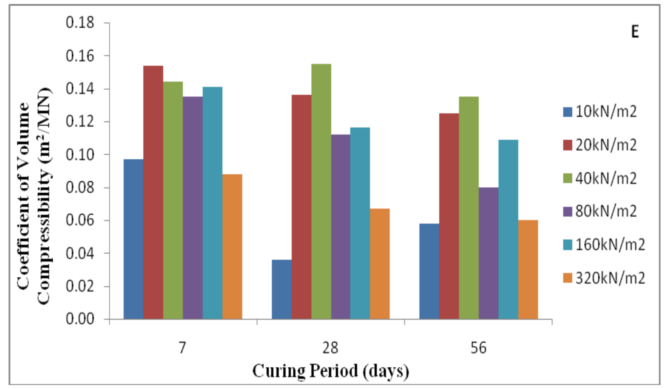
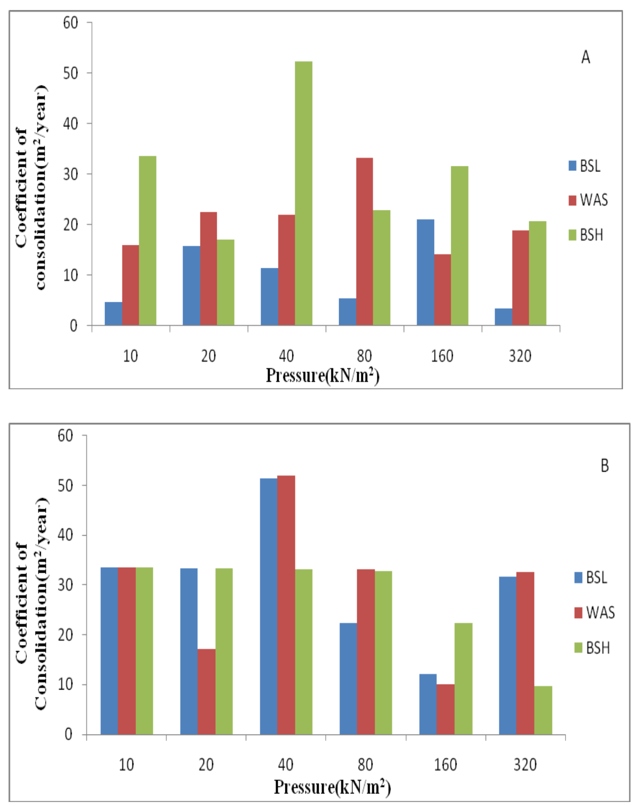




**Figure 11** Coefficient of volume compressibility with curing period for (A) 0%, (B) 4%, (C) 8%, (D) 12% and (E) 16% RHA contents.

### *3.3.5 Coefficient of consolidation ($C_v$)*

**Influence of Compactive Effort**

The coefficient of consolidation was determined using the square root of time method. Plot of $C_v$ with RHA content is shown in Figures 12a-e. Generally, no trend was established with rise in both the compactive effort and the RHA content. At 4% RHA content for BSH compactive effort, $C_v$ decreased continuously from 33.6 to 9.72 $m^2$/year. While at 12% RHA content for BSL compactive effort, at pressure of 10-20 kN/$m^2$ a rapid change occurred from 52.2 to 12.9 $m^2$/year before an increase at 40kN/$m^2$ and then it dropped from 32.8 to 9.9 $m^2$/year. The drop in coefficient of consolidation is related to the rearrangement of the soil particles. Similar decreasing trend was reported by Ikeagwuani [5].



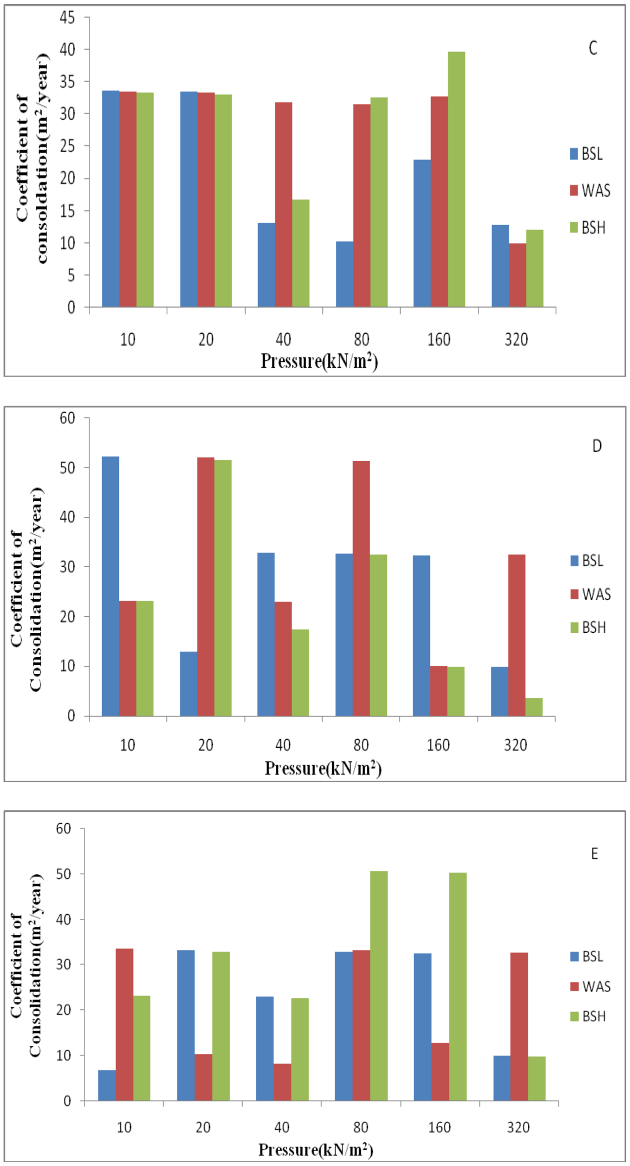
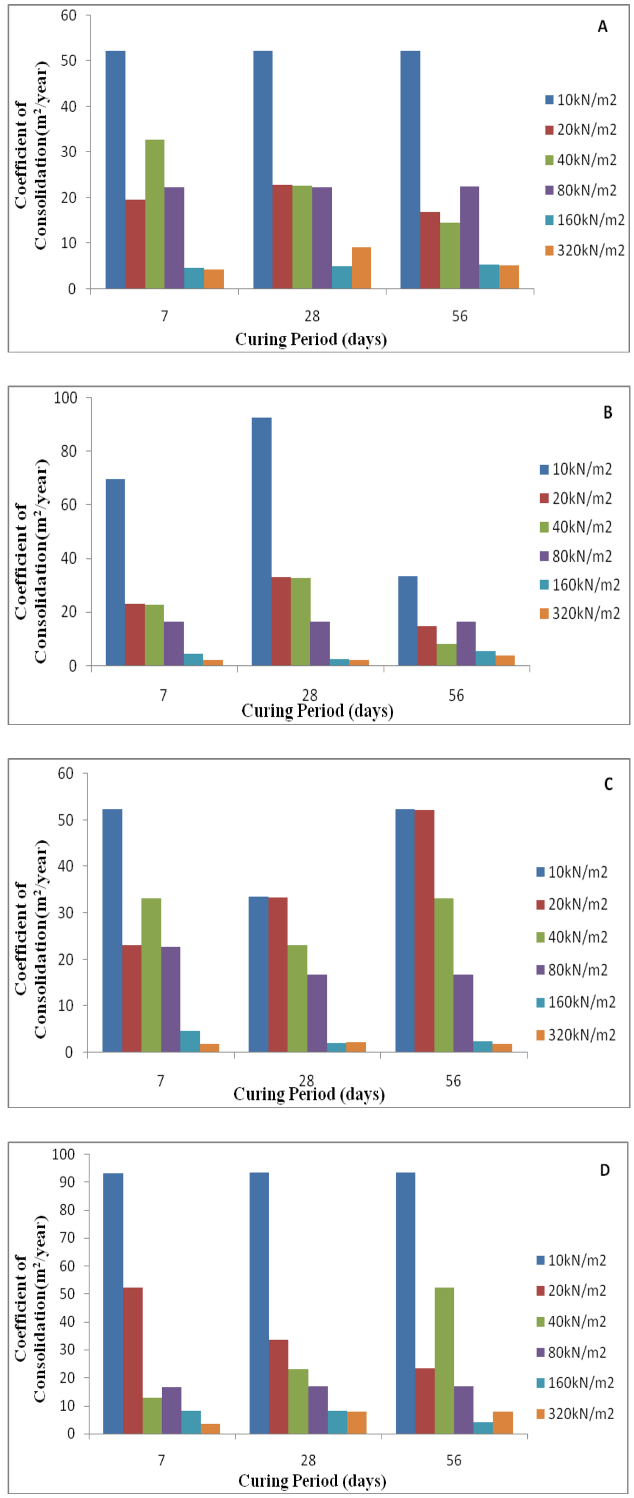
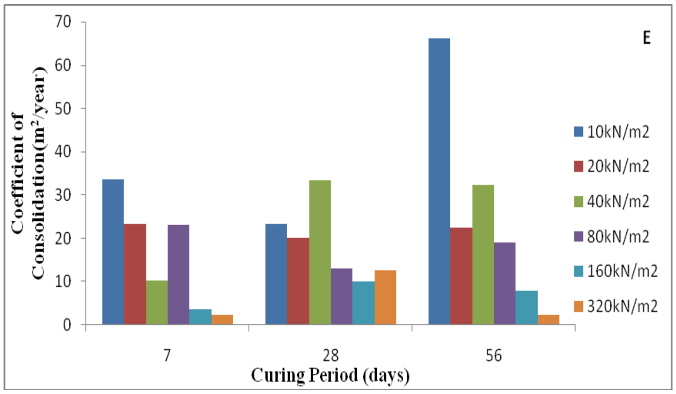



**Figure 12** Coefficient of consolidation (Cv) at different compactive efforts with pressure for (A) 0%, (B) 4%, (C) 8%, (D) 12% and (E) 16% RHA contents.




### Influence of Curing Period

Plot of Cv with increase in curing period is revealed in Figures 13a-e. No observable trend was established with rise in curing period. The haphazardness of the values can be observed to originate from the widely varying values obtained by graphical means at the same quantity of RHA. Cation exchange reaction and physic chemical changes within the soil matrix did not have significant effect on the treated soil. However, this is not in agreement with literatures [5,31].




**Figure`13** Coefficient of consolidation (Cv) with curing period for (A) 0%, (B) 4%, (C) 8%, (D) 12% and (E) 16% RHA contents.

## 4.0 CONCLUSION

The Lateritic used in this study was treated with 0, 4, 8, 12, and 16% RHA to evaluate the soil consolidation properties. Results is summarized as follows

1. The percentage fines reduced from 50.29 to 43.08%, the MDD declined from 1.72 to 1.42Mg/m$^3$ and OMC increased from 16.5 to 27.3% at 0 and16% RHA respectively.
2. The pre-consolidation pressure rise with incline in RHA content and also with increase in both compactive efforts and curing period with exception in some case. At 12% the pre-consolidation pressure increased from 65 to 66.5kN/m$^2$ at 7 days and 56 days respectively. Increase in RHA content caused a decrease in compression index and swelling index.
3. Compression index decreased with increase in both compactive efforts and curing period. There was no apparent trend detected in the swelling index with curing period. As the compactive efforts increased, Cs decreased.
4. Mv and the Cc reduced with treatment. It is observed that at 8% and above, the mv at each pressure lessened with increase in curing period. No universal trend was established for Cv with increase in both compactive efforts and curing.
5. Based on the obtained results, RHA can be more profitably use as an admixture for treatment of lateritic soil to develop its engineering characteristics.
6. This study has proven that consolidation properties of RHA treated soils can be substantially improved by curing before working loads are applied on them. A curing period of at least 28 days using 12% RHA compacted at energy level of BSH is recommended for optimal results.

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